CANADIAN POLICE RESEARCH CENTRE

CENTRE CANADIEN DE RECHERCHES POLICIÈRES

Technical Report

TR-06-2008

Development of an Aged Armour Replacement Protocol Phase One Report

March 2008

Prepared by

Biokinetics and Associates Ltd.

For the:

Canadian Police Research Centre

This report is a publication of the Canadian Police Research Centre.
For additional copies or further information contact:

Canadian Police Research Centre (CPRC)
Defence R&D Canada – Centre for Security Science
Building M-23a, 1200 Montreal Road
Ottawa, ON K1A 0R6
Telephone: (613) 993-3996
Fax: (613) 949-3056
www.cprc.org

Centre canadien de recherches policières (CCRP)
R&D pour la défense Canada – Centre des sciences pour la sécurité
Édifice M-23a, 1200, chemin de Montréal
Ottawa (Ontario) K1A 0R6
Téléphone : (613) 993-3996
Télécopieur : (613) 949-3056
www.cprc.org

Development of an Aged Armour Replacement Protocol

Phase One Report

Report No.:
R07-16

Date:
NOVEMBER 30, 2007

Status:
Commerical in Confidence

Prepared for:
Steve Palmer

Canadian Police Research Centre
1200 Montreal Rd.
Ottawa, Ontario
K1A 0R6

Authors:
Christopher Withnall

Biokinetics and Associates Ltd.
2470 Don Reid Drive
Ottawa, Ontario, K1H 1E1
Canada

tel: (613) 736-0384
fax: (613) 736-0990
www.biokinetics.com

Preface

This report describes the Phase I work of a program for the development of a protocol for assessing the service life of aged body armour among Canadian Police Forces. The work herein is based on Biokinetics Proposal R07-50 and National Research Council contract file number 643168.

There are no budgetary estimates presented in this report version.

The opinions expressed herein are those of Biokinetics and Associates Ltd. and do not necessarily reflect those of the Canadian Police Research Centre.

(this page intentionally left blank)

Table of Contents

List of Tables

1. Introduction

During a meeting of the Board of Directors of the Canadian Association of Chiefs of Police (CACP) a motion was passed "that the CACP ask the Canadian Police Research Centre to investigate the issue of life expectancy of soft body armour with respect to issues including the manufacturer's warranty period and replacement time". For clarification, body armour in differing designs can be used to defeat or at least mitigate the effects of either ballistic or stab threats or both. For some applications, particularly in corrections, stab threats may also be of concern, but this report deals only with ballistic armour.

The ballistic performance of soft body armour is measured according to various standards. The most widely referenced in Canada is the US National Institute of Justice (NIJ) standard 0101.04, however there are also North American military standards (such as US MIL-STD-662F), European standards (HOSDB), and standards developed specifically by various police services such as the RCMP (G.S.1045-177). These standards describe the minimum performance of new product at the time of certification and/or delivery.

Soft body armour usually carries a manufacturer's warranty. Typically this is five years. A reasonable person might assume that the warranty guarantees performance to the certified level for its duration. However, the exact terms of warranty are often not stipulated by the manufacturer nor demanded by the purchaser. The user presumes good bullet-stopping capacity of his vest despite its age and wear, but there currently is no standard that mandates the performance of armour as it ages in use. That said, the NIJ has under development a replacement for 0101.04 (0101.06) which will include a protocol for artificial accelerated aging of ballistic armour to address this concern.

In the meantime, users of body armour are legitimately concerned about when to replace their existing product. Replacement immediately at expiration of warranty might offer some assurance that new product performance will be maintained throughout service life, but only if the warranty in fact assures performance. On the other hand, if it could be scientifically demonstrated that useful life might be extended for some time past five years without compromising user safety, the life cycle cost of the armour could be dramatically reduced. Naturally, this is an issue affecting not only management who are interested in budget effects, but also members of the police service and/or unions who are directly affected by the armour performance. In some cases this has even become an issue for the courts, citing worker safety.

It will likely be some time before full implementation of the new NIJ standard 0101.06 is effected and even then, it will be a number of years before armour bought under that standard will replace existing product bought under previous

standards. As a result, an approach to validating the performance of aged armour would be of benefit. Indeed, even with products complying with 0101.06, verification of the actual performance of aged armour will be necessary for some time to prove the validity of the new standard and its simulated artificial aging process.

The NIJ 0101.04 standard tests armour for two performance measures. The first is Penetration and Backface Signature (P-BFS). The second is Ballistic Limit (BL). They are described in the standard as follows: "The first test series, P-BFS, is designed to measure the overall ballistic performance of the armour according to pass/fail criteria. The second test series, baseline BL determination, is a test to penetration failure and is designed to statistically measure penetration performance. No pass/fail criteria are attached to the BL portion of the testing." (Note that the current draft of the 0101.06 standard does include V50 test results in the proposed pass/fail criteria.)

For P-BFS testing, a number of specific test rounds are fired at the armour at specified velocities. Penetration of the armour is not allowed and the allowable amount of measured deformation of a clay backing material is also limited in order for the armour to meet the pass/fail criteria.

For BL testing, the same specific test rounds are fired at the armour, but at varying velocities until it is possible to determine V50 , which is defined in the standard as "the velocity at which a projectile is expected to completely penetrate an armour component (sample, panel or ballistic panel) 50% of the time (V50). This velocity is also the velocity at which a projectile is expected to be stopped by the armour 50% of the time (V50)."

Both of these test approaches, in modified form, are useful in investigating the performance of aged armour as well.

One of the larger costs associated with testing of armour is the actual cost of the armour itself, which is tested to destruction. During a recent program to investigate the effects of aging on a specific material (Zylon), the Office of Law Enforcement Standards (OLES) utilized a modified NIJ 0101.04 test protocol, which required fewer shots for the P-BFS series and thus also significantly reduced the number of vests required. This allowed them to cost-effectively investigate a large cross section of in-use armour to get an indication of performance.

At the same time, BL (V50) testing was performed, again with a reduction in numbers of vests required. While there are no pass/fail criteria associated with the BL numbers, trends in V50 over time may be established. Typically, the V50 is significantly greater than the velocities required for P-BFS testing. If, over time, it can be shown that the V50 is moving lower and closer to the P-BFS numbers, a prediction might be made as to when P-BFS testing will be likely to show a failure.

Biokinetics has successfully used both of these modified NIJ test protocols to investigate the performance of aged armour in a cost-effective manner.

One of the major areas for consideration in all of this is the statistics associated with determining meaningful sample sizes and how this relates to things such as the size of police force, environmental differences, whether broader populations can be considered (multiple forces) and so on. Some of the OLES work has shown that simple aging, in the absence of other factors, is not likely to cause deterioration in performance, however, exposure over time to improper usage or storage can result in factors such as bacterial or fungus growth, obvious fold lines, fraying of ballistic panels, the introduction of water and so on, all of which can adversely affect ballistic and stab performance. A large force (RCMP, OPP or QPF for example) with numerous operating locations and scenarios might require samples to be taken from a number of locations and treated as separate batches, since the usage environments will vary greatly from location to location. A very small municipal force may require a very large percentage of their overall population as a test sample simply to arrive at a meaningful statistical sample size. Thus, in the development of any proposed approach, statistical analysis will be an important factor.

To summarize, we have the ingredients for an extraordinarily important research and development effort, to develop a replacement protocol for aged body armour. In this report, we will discuss Phase One activities, which include a background investigation of vest warranty information, a report on similar work by the NIJ, a review of statistical elements for meaningful results, estimates on the availability of used garments from Canadian forces to support this study, and finally a work plan and budget proposal for the development of a scientific approach towards the replacement of soft body armour.

2. Phase 1: Background and Work Plan

The following sections describe the background research in developing a work plan for an aged armour protocol.

2.1 NIJ and OLES Activity on Aged Armour

On June 23, 2003 Police Officer Edward Limbacher of Forest Hills, Pennsylvania was shot by a drug suspect and was struck in the arm and abdomen. The .40 calibre S&W round, of conventional construction, penetrated his body armour approximately 6 inches to his right of centreline and 4 inches above the bottom of his panel, entering his abdomen and lodging near his spine. The round was not removable surgically and Limbacher remains disabled from his injuries. Officer Limbacher was wearing a Second Chance Ultima® armour made from Zylon.

The Forest Hills shooting was the first case reported to the NIJ where a certified vest failed to prevent penetration by a round it was designed to defeat. The incident prompted then U.S. Attorney General John Ashcroft to introduce the Body Armour Safety Initiative on November 17, 2003. The NIJ was directed to:

- Initiate an examination of Zylon-based bullet-resistant armour (new and used),
- Analyze upgrade kits provided by manufacturers to retrofit Zylon-based bullet resistant armour, and
- Review the existing process by which bullet-resistant armour is certified.

The following is an account of subsequent activities by the NIJ and the Office of Law Enforcement Standards (OLES) to understand why Limbacher's vest failed and what needs to be done to address this in the future. It is based on communications with Mr. Kirk Rice[1] of the Office of Law Enforcement Standards a review of three status reports on the Body Armour Safety Initiative[2,3,4] , and

[1] Kirk Rice, Program Manager, Weapons & Protective Systems, Office of Law Enforcement Standards, 100 Bureau Drive, Bldg 225, Rm A323, Gaithersburg, MD 20899-8102. (kirk.rice@nist.gov)

[2] Status Report to the Attorney General on Body Armour Safety Initiative Testing and Activities, March 11, 2004.

[3] Supplement 1: Status Report to the Attorney General on Body Armour Safety Initiative Testing and Activities, December 22, 2004.

[4] Third Status Report to the Attorney General on Body Armour Safety Initiative Testing and Activities, August 24, 2005.

participation in the NIST Workshop on Body Armour and Ballistic Fibre Research (Gaithersburg, MD, Oct. 3-5, 2007).

2.1.1 Forest Hills Simulation by Artificial Ageing

In immediate response to the Forest Hills incident, fibres from the back panel of Limbacher's vest were measured for tensile strength and found to be 30% weaker than from a new exemplar vest. Thirty-two new Zylon ballistic panels were tested, sixteen "as supplied" by the manufacturer and sixteen after weakened by exposure to temperature and humidity in a conditioning chamber for five months. Fibres from the conditioning chamber were removed every two weeks and subjected to tensile tests and chemical changes. A ballistic performance study looked at the material tensile strength, bullet type, barrel twist, shot angle and shot location. However, no combination of factors produced a penetration of any panel nor reproduced the Forest Hills vest results satisfactorily. It was speculated that perhaps the back and front panels of the Forest Hills vest were different, the static tensile tests do not simulate the dynamic tension fibres in a ballistic test, folding and flexing may have caused localized damage not observed in the back panel, or perhaps unknown chemical agents may have damaged the fibres.

2.1.2 Preliminary Field Samples Tests

Used armours were called back from the field. A total of twenty-eight heavily worn and out-of-service Zylon vests aged 8 months to over 5 years and representing four manufacturers were obtained from law enforcement agencies across the US. The front panels underwent ballistic proof tests, and penetrations were observed in 12 of the 28 samples (43%). For many that passed the penetration test, the backface signature (i.e. the dent left in the clay backing material) exceeded maximal allowance.

Ballistic limit, or V50 tests, were performed on the back panels of all 28 vests, 19 of these were compared to V50 data from identical new vests. Nine of the 19 V50 ballistic limit results were significantly lower than the new vests.

The back panels of 22 vests were examined for fibre tensile strength, and compared with that of new fibres. Yarn tensile strength loss averaged 41%, with a minimum loss of 11% and a maximum loss of 61%.

The NIJ conceded that the above testing results were limited by the small sample size, the lack of randomness of the samples, the few models represented and the lack of background history on the environment and use (or misuse) of the vest. Despite these limitations the results supported the notion that the ballistic performance was degrading over time in Zylon–containing armour.

2.1.3 Comprehensive Field Samples Tests

The OLES consulted with the Statistical Engineering Division within the National Institute of Standards and Technology (NIST). A plan was designed to obtain a statistically relevant sample of 500-1000 used Zylon armours from the field and execute a comprehensive test protocol to look fully at the causes of degradation. Samples were to be divided by 5 different climatic regions, 5 different age categories and 4 different manufacturing categories. By looking at armour from different climatic regions, the effects of temperature, humidity and UV light on armour performance could be examined. The manufacturing categories would examine the weave type, protective coverings, ballistic layers and stitch patterns. Ballistic testing coupled with materials and chemical analysis would isolate the cause of ballistic failures.

The OLES and Statistical Engineering division devised a plan to use the ZIP code of a particular police department cross referenced with the US climate regions to obtain samples exposed to known temperature and humidity ranges. However, when agencies were contacted, it was discovered that manufacturer had already initiated buyout or replacement programs. Many agencies would not give up old vests or did not know where the used vests were. Initially, the NIJ planned to replace the vest with a new one, but that raised liability flags. Instead, funding was offered to replace a surrendered vest (after eventual agreement on whose budget would be used). That in turn resulted in suspicious situations where armour was offered up voluntarily, sometimes garments of dubious origin where the model being offered did not match what was otherwise in use by that force.

Unfortunately, the NIJ had no authority to compel the surrender of armour for lab testing. In hindsight, the OLES muses that it might have been more effective for court power to subpoena vests for evaluation, despite the hurdles of doing so across many legal jurisdictions. After all was said and done, only 75 used Zylon armours were obtained for comprehensive testing.

Laboratory tests on the 75 samples were analyzed by ballistic performance, age, amount of Zylon (relative to other materials) in the shot pack, thread count and overall armour condition. With few exceptions, all garments were found to have suffered degradation, leading to the following conclusions.

- Ballistic limits of used armour samples were generally less than new samples.
- Zylon yarns from used samples showed degraded tensile strength.
- Age and visual examination were poor indicators of performance.
- Samples that did not allow penetration showed higher than allowable back face signatures.

2.1.4 Further Applied Research Activities

To complement the ballistic test program, the NIJ initiated a number of research activities including:

- Chemical, mechanical and physical properties of Zylon,
- Factors that contribute to the degradation of Zylon (i.e. heat, humidity, UV, folding),
- Correlation of chemical and mechanical changes with ballistic performance,
- A look at how moisture or other trace materials in virgin fibre might lead to problems long term,
- Development of an accelerated ageing process to predict the future performance of Zylon.

Zylon is also known by its chemical name poly(p-phenylene benzobisoxazole) or PBO. PBO can be thought of as a long chain of repeat units that are bonded together in a linear arrangement. Millions of these polymer chains arrange themselves into a long thin fibre. Hundreds of these fibres bundled together form a yarn, which is then woven into fabric. A large body of scientific literature reveals that the oxazole ring, the five-member ring that occurs within the chemical structure of PBO, has characteristics that cause it to degrade from moisture and light exposure. Using Fourier transform infrared (FTIR) spectroscopy, changes to the oxazole ring can be observed as the fibres degrade mechanically. This in turn correlates with the ballistic degradation observed in both used and artificially aged vests. This may be a method for predicting the performance of a vest without destructive testing. For instance, if a coupon of fabric was added to each vest at manufacture, and was thus exposed to the same environment as the shot packs, it could be harvested for periodic testing to indicate ballistic performance. However, this is very specialized testing and IR spectroscopy equipment could be prohibitively expensive as a solution for routine performance checks. Further, the correlation is applicable only to Zylon-based armours.

A major conclusion from this analysis is that Zylon fibres isolated from moisture suffered no degradation. Even though Zylon packs may have been stitched within waterproof membranes, moisture vapour such as from sweat and humidity, due to their smaller molecule sizes, could still pass into the fibres. A hermetically sealed pouch could prevent contamination of the shot packs.

2.1.5 NIJ Interim Requirements for Bullet-Resistant Armour

Up to this point, the NIJ had focused only on Zylon ballistic material. On September 26, 2005 the NIJ announced that all body armours previously listed as certified would be removed from the compliance list, and only models

demonstrating compliance with interim modified tests would be allowed back on. These interim standards require that comprehensive descriptions of the materials and construction of a submitted vest be documented. A manufacturer must attest that no materials identified by the NIJ as being not suitable are used in the garment. Furthermore, new tests are included for moisture absorption, increased numbers of shots, and an enhanced description of how pass/fail criteria should be measured is provided.

2.1.6 Artificial Ageing and Continued Research

The NIJ and OLES continue to research ways to subject ballistic armour to accelerated ageing. The aim of course is to introduce a test method that would cause the garment to suffer the same degradation expected over its service life, but do so in a short period of time. Thus a test done after this artificial ageing would verify the garment's future performance.

The NIJ prefers the term "environmental conditioning" because there is no way to correlate definitively artificial with real ageing. The aim is to reproduce some sort of physical, hydrolytic and temperature fatigue in armour. Current research includes tumbling, folding and ultra-high humidity exposure within a controlled environmental chamber. What remains unclear is that accelerated exposure to these elements affects ballistic fibres in the same manner as the longer term general use.

What also remains unclear is how ballistic materials other than Zylon will react to artificial ageing, or environmental conditioning. So far, the NIJ's research has centred solely on Zylon, since that was the material that failed in Forest Hills. We do not know how the NIJ research, focused on Zylon, will translate to other materials. Manufacturers of other ballistic fibres, such as DuPont (Kevlar), Honeywell (Spectra),and DSM (Dyneema) have reported on their own tests for degradation and ageing, but these can only be completely credible if confirmed independently.

The NIJ and OLES are very interested in extending their research to include other ballistic materials, but that requires access to aged armour, and that has proven to be a very non-productive undertaking within the United States. At the NIST, the OLES researchers and scientists have access to tensile fibre grip test machines, infrared spectroscopy and computer controlled environmental chambers. They can do microscopic examinations of "kink-banding" where discontinuities in fibres can cause weak spots. They are eager to study laminated fibres such as Spectra where they are not woven, but rather aligned uniaxially, sandwiched and heated to bond together, thus preventing moisture absorption and giving structural rigidity. They are currently purchasing a multi-fibre tensile machine for higher volume testing.

Later in this report we will discuss the feasibility of a partnership between the NIJ's research power and the Canadian supply of aged armour available for study.

2.2 Manufacturer Warranty and Replacement Issues

The stated warranty period for most standard production ballistic vests is five years. But what is the basis for the five-year period? In the NIJ guide to selection of body armour[5] it suggests that this 5-year period reflects the guidelines established by the early research begun in 1983 by DuPont[6] as well as an independent 1986 NIJ evaluation of aged armour[7]. Both research studies included exclusively Kevlar armour and both included vests that had been in use for as long as 10 years. While the NIJ found the used vests had ballistic properties that were indistinguishable from those of unused armour manufactured at the same time, DuPont researchers at the time recommended re-evaluation of vests in the 3-5 year range. Before the Forest Hills affair, however, the NIJ recommended that no re-evaluation testing was necessary until a five year period of use.

Since 2005, the NIJ has conceded that there "is no accepted test protocol to evaluate the performance of used body armour over a period of years of typical law enforcement use." However, it has put emphasis on the manufacturer to "affirmatively demonstrate to NIJ that their body armour will maintain its ballistic performance during the declared warranty period."

We conducted an informal poll of six manufacturers of body armour, focusing on a combination of Canadian and larger suppliers. These notes are provided in Table 1. The terms of warranty vary among manufacturers, some explicitly identifying only materials and construction, others implying that ballistic performance is guaranteed for the duration of the warranty period. One manufacturer actually offers a sizeable insurance sum should their product fail. With the exception of Northern Defence, who candidly indicated that their client, the RCMP, did not require a warranty, the ubiquitous five year warranty period is clearly evident.

---

[5] "Selection and Application Guide to Personal Body Armor", NIJ Guide 100–01 (Replaces Selection and Application Guide to Police Body Armor, NIJ Guide 100–98), November 2001, Published by: The National Institute of Justice's National Law Enforcement and Corrections Technology Center.

[6] "Personal Body Armor Facts Book", DuPont, June 1994.

[7] Frank, Daniel E., "Ballistic Tests of Used Body Armor," NBSIR–86–3444, National Bureau of Standards (U.S.), August 1986.

Table 1: Poll of warranties offered on ballistic armour.

Manufacturer	Contact	Ballistic Materials *	Warranty Claimed	Explanation of Warranty	Testing of Aged Armour
Ten4 (Atlantic)	André Beaudoin General Manger (819)365-4800	Goldflex, Twaron	5 years for materials and workmanship of the ballistic panels with a 10 million dollar insurance policy against ballistic penetration during the warranty period.	It is the industry standard.	They have not done any internal testing of their own aged vests.
Point Blank	Neil Nadler Special Projects Officer (800)413-5155	Kevlar	5 years for materials and workmanship (seams, visible defects). The contact also said that vests are warranted for ballistic penetration for the 5 years but would not elaborate beyond that statement.	It is the industry standard which is based on research done in the 1980's by DuPont that showed that the effectiveness of aramid materials to ballistic impacts degrades after 5 years.	Claim to have done testing of aged armour. No further details available.
Pacific Safety Products (PSP)	Jenna Alain Customer Service Manager (250)491-0911	Goldflex, Twaron, Dyneema, Kevlar, Zylon	Their warranty covers materials and workmanship of the ballistic panels for 5 years.	It is the industry standard.	Claim to have done testing of their aged vests. They "pull back vests" and do ballistic tests. No further details available.
Armor of America	Andy Stewart VP of Sales (334)321-0762	Kevlar, Dyneema	It is a 5 year warranty that covers "ballistic integrity" of the ballistic panels under normal wear and tear.	It is the industry standard.	Suggested that the 5 year warranty requires old vests to be sent to the NIJ for testing and confirmation.
Northern Defence	Julie Glenister (416)803-5076	n/a	They do not have a warranty on the vests that they currently sell to the RCMP.	The RCMP did not require it in their contract.	None
Second Chance	No contact responded. (800)253-7090	Twaron	18 months for the carrier and 5 years for the ballistic panels to perform as certified.	n/a	n/a
* information obtained from product literature and web searches, not the contact.					

What is also evident, even among this small sample, is the wide range of ballistic materials that are used. These included Kevlar, Dyneema, Twaron, Goldflex (Spectra) and Zylon. We know about Zylon's recent extensive study, as well as Kevlar's in the past, but the potential degradation of the others remains unclear. We mention this not in disrespect of the fibre manufacturers, who employ expert scientists and devote much resources towards research and development to perfect their products. However, based on the Zylon case study, what is clear is how much of the final performance of a vest relies on proper ballistic material packaging and end consumer use of the product.

Even after environmental ageing protocols are successfully invented and adopted that simulate long term exposure to moisture, heat, ultraviolet light, folding and flexing, such as those proposed in the new revision to NIJ 0101.04 (named in draft form NIJ 0101.06), the burden of a replacement protocol will continue to be placed on the individual law enforcement agency. The NIJ has

recommended the replacement of any aged armour containing Zylon, but for other vest materials they continue to recommend ballistic tests on randomly sampled used armours to indicate whether or not to continue using them. The IACP National Law Enforcement Policy Center[8] is currently considering the reaffirmation of a similar policy guideline to simply test armour yearly once the stock becomes three to five years old, and to recommend that the decision to replace body armour is a question that must be decided by each individual agency based on its own fiscal situation, philosophical view and random test results.

In Canada, forces are faced with a similar predicament. The expertise necessary to select an appropriate test sample, commission and interpret test results, coupled with health and safety and labour relations pressures, often results in a simplistic five-year mandatory replacement. However, in Canada there are several exceptions. We obtained vest replacement intervals from several major Canadian Police Forces[9], tabulated in Appendix A. The RCMP, for instance conducts routine ballistic tests on samples of their aged armour, and finds that approximately seven years is the typical replacement interval. The Quebec and Montreal Police forces adopt a ten year replacement interval, and further mentioned that older armour is assigned to officers who must have it, but will unlikely ever use or need it. Halifax adopts a ten year cycle based on informal non-standardized tests using service weapons in firing ranges. Forces that simply adopt a 5-year cycle appear not to do any tests.

What is clear from this informal poll is that there remains no common protocol for the replacement of aged armour. Those forces that adopt a simple five year policy might be discarding serviceable armour prematurely. Those forces extending service life to ten years might not be selecting an appropriate statistical sample such that their tests reflect the population of users.

2.3 Available Armour Database

To gain an understanding of the number of vests in service, the number decommissioned annually and the number of available used armour for future testing, a memo was issued at the CACP conference in August 2007. This memo, issued by Mr. Steve Palmer of the CPRC, requested that the Chiefs direct their purchasing officer, or whomever else might be responsible for aged armour, to contact Biokinetics and Associates and answer a few questions. This memo is reprinted in Appendix B.

---

[8] IACP National Law Enforcement Policy Center "Body Armor: Concepts and Issues Paper" originally published June 1990, revised April 1999, submitted for reaffirmation April 2007.

[9] More information about the polling of Canadian Police Forces if described in Section 2.3.

Unfortunately, the response rate was very poor, possibly owing to its last-minute introduction at the August 2007 meeting. Not being tabled as an agenda item meant it was not documented in the minutes, and presumably got lost in the shuffle. However, we are confident that with more timely requests, the Chiefs' support for the development of an aged armour protocol will in turn result in the necessary data gathering from the forces.

We took the initiative to contact directly the largest Canadian Police Forces, using both the RCMP Pay Council Comparator Universe and the Canadian Centre for Justice Statistics "Police Resources in Canada, 2007"[10] to select them. These included the RCMP, QPF, OPP, Toronto, Montreal, Vancouver, Calgary, Ottawa, Edmonton, Winnipeg and Halifax forces. The number of sworn officers represented by these cities are summarized in Table 2 below. If we focus just on these major forces, we account for 41,726 of the total 62,482 officers in Canada, or 67%.

Details on the quantities and makes of armour, as well as their other details on warranty issues, are provided in Appendix A. Although we were unable to make contact with Toronto, the remaining estimates of the body amours in the various police forces compare very favourably with the published statistics on officer numbers in Table 2.

What was surprising, however, was the relatively low estimates on the quantities of used armour that could be made available for study. Granted these are very rough estimates, based on informal telephone conversations, and some forces did not have numbers available at that moment, but we only confirmed fewer than 100 aged armours for testing. Even by conservative estimates, assuming that one in ten vests is replaced annually, that should leave us with over four thousand aged armours removed from service each year. Obviously, with direction from the chiefs, clearer numbers will be available in the future.

[10] Statistics Canada, "Police Resources in Canada, 2007", Catalogue 85-225-XIE, Canadian Centre for Justice Statistics.

Table 2: Number of sworn officers of Major Police Forces in Canada.

RCMP	15,481
Provincial (OPP & QPF)	9,043
Toronto	5,558
Montreal	4,406
Vancouver	1,309
Calgary	1,604
Ottawa	1,210
Edmonton	1,364
Winnipeg	1,275
Halifax	476
Sub-total target forces:	*41,726*
Total Canadian officers:	*62,482*
Percentage of officers represented:	*66.8%*

2.4 Statistics

A program to develop a protocol for the replacement interval of aged armour relies on a multitude of factors, and a comprehensive statistical basis for analyzing and applying the data. Statistics is a mathematical science pertaining to the collection, analysis, interpretation or explanation, and presentation of data. It is applicable to a wide variety of academic disciplines, from the physical and social sciences to the humanities. Statistics are also used for making informed decisions.

Statistical methods can be used to summarize or describe a collection of data, otherwise called *descriptive statistics*. Descriptive statistics can be used to summarize the data, either numerically or graphically, or to describe the sample. Basic examples of numerical descriptors include the mean and standard deviation. Graphical summarizations include various kinds of charts and graphs.

Alternatively, *inferential statistics* is used to model patterns in the data, account for randomness and draw inferences about a larger population. These inferences may take the form of answers to yes / no questions (hypothesis testing), estimates of numerical characteristics (estimation), descriptions of association (correlation), or modeling of relationships (regression). Other modeling techniques include analysis of variance (ANOVA), time series, and data mining.

In applying statistics to a scientific, industrial, or societal problem, one begins with a process or population to be studied. This might be a population of people in a country, of crystal grains in a rock, or of goods manufactured by a particular factory during a given period. For practical reasons, rather than compiling data about an entire population, one usually studies a chosen subset of the population, called a sample. Data are collected about the sample in an observational or experimental setting. The data are then subjected to statistical analysis, which serves two related purposes: description and inference.

Both descriptive and inferential statistics comprise applied statistics. For aged armour investigation, we will primarily adopt inferential statistics, and in doing so try to estimate the remaining service life of a population of police body armour based on the test results of a small sample.

The concept of correlation is particularly noteworthy. Statistical analysis of a data set may reveal that two variables (that is, two properties of the population under consideration) tend to vary together, as if they are connected. For example, a study of the V50 of used armour vary together by age and model. The two variables are said to be correlated. Another model's performance may not be adversely affected by age alone, but rather visual condition for example. However, one cannot immediately infer the existence of a causal relationship between the two variables, in other words, how or why one affects the other.

For body armour, the we need to make some generalizations about the performance ability of aged garments. When making generalizations we need to understand the population we are generalizing and the limitations of the statements. Some statements may be true for some population (or subset of a population) and not for others - for example, we may be able to conclude that "well maintained" armour (always hung in locker at end of shift) continues to perform well after X years, but "marginally maintained" armour ceases to perform after Y years of use. To be able to draw such conclusions, we must identify the potentially important characteristics up front.

Going hand-in-hand with the idea of understanding the population and its important characteristics is the statistical principle of representative sampling. To make broad statements about a population, we must be sure we considered a representative sample in the testing. For example, if we were attempting to make a statement about used armour in Canada., testing a large number of armour donated only by Vancouver would not be adequate because it fails to include armour that is subject to the northern cold, for example, which may be an important factor. By identifying these characteristics up front, we can employ stratified random sampling which helps ensure the representation we desire.

Some of these characteristics may include:

- Manufacturer
- Ballistic material

- Total age of armour
- Number of years in service
- Number of years in storage
- Type of storage facility (climate controlled, etc.)
- Region (climate) of use
- Gender of user
- User activities (patrol car, foot patrol, etc.)
- User maintenance practice (always hung away from sunlight, thrown in back seat of car, etc.)

The sample size needed for successful implementation of a protocol may depend on all or only a few of the above parameters. But ultimately a working aged armour replacement protocol will be limited by budget. How many vests need to be tested versus how much money is available to test them? This is a reality to be faced, in which case the limitations of the conclusions need to be pointed out when the testing is arbitrarily limited by budget. The factors associated with the sample size will need to be addressed on a case by case basis.

3. Work Plan for Phase 2: Development of an Aged Armour Protocol

This Phase 1 report examines the background issues of aged armour, and prepares the following work plan towards developing an aged armour protocol. As discussed earlier, the primary police forces across Canada do not follow any common guidelines on how to decide an armour's useful service life. Each has its own policies and practices, which may or may not be ideal. While the five year warranty policy might be considered a minimum criterion for discarding used vests, there could be considerable cost savings associated with extending service intervals through a systematic and statistical verification protocol, presuming of course that the safety of the officers is not compromised.

We shall refer to the actual development of this protocol as Phase 2, the deliverable being a working document describing the factors associated with sampling and testing used armour, as well as the interpretation of the test data, all towards arriving at a decision on safely extending service life. The aim is that a police force could follow the guidelines and come to their own systematic conclusions.

Verification that this protocol is effective in real life would be done in a future Phase 3, where one or two representative forces would engage in a pilot study of sampling and testing, with the support of Biokinetics and Associates Ltd.

3.1 Detailed Ballistic Armour Data

The CPRC began this work by request from the CACP. We therefore know that the CACP will be eager to participate in and facilitate the gathering of data on the armour supplies of each force. In Section 2.3 we described the limited information on armour numbers obtained from the largest sized police forces in Canada. We also showed that these largest forces combined to represent two-thirds of the total Canadian police force. On the premise that smaller forces may not have the resources to conduct a sophisticated replacement policy, and could simply follow the lead of the larger forces, we think that the participation of only the largest forces listed will be needed.

With the support of the chiefs, we will tabulate the purchasing, distribution, service life and decommissioning of the ballistic armour from each participating force. We hope to secure information on details of usage types, climatic conditions and care. The exact information needed will be a back-and-forth with the design of a statistical model (see Section 3.3). A universal protocol will rely on data commonly available to all users, and which can not be overly

burdensome to adopt. But at this stage, we will aim to collect as much information as possible about the life cycle of body armour in the field.

3.2 CPRC/OLES Collaboration Agreement

Biokinetics has introduced the notion of a joint collaboration between the CPRC and the OLES. We mentioned earlier that the OLES, under the umbrella of the NIST, has done extensive analysis on Zylon armour, and has a vast arsenal of scientific tools, but has little or no access to aged armour of other types to expand their research. We propose that samples of used armour be made available for their study and in return the CPRC gains access to their facilities and scientific and statistical expertise.

Conversations between Biokinetics, the OLES and the NIST's Statistical Engineering Division (SED) have been very positive. Within a reasonable scope of activity, the OLES would fit their analysis of Canadian used armour under their existing operating budgets. A research partnership streamlines things considerably, since it is very cumbersome for governmental dollars to cross the border.

However, this relationship, and the project expectations, timelines, responsibilities and deliverables from each party will need to be formalized and documented. We anticipate a joint meeting at the OLES including representatives from Biokinetics and the CPRC to finalize this task.

3.3 Statistical Plan

A statistical plan will be formulated based on the information available on the armour among participating police forces. This sounds obvious at first, but we must remember that statistical "wishful thinking" can cause test numbers to rise drastically. Our aim is to keep the protocol as simple as possible, while maintaining control of relevant and easily documented variables (for example, make, model, age, service history) rather than more esoteric variables (for example sweatiness, laundry detergent).

Once all the available information is obtained from all participating departments, we look for common data tabulations, and if necessary go back to some forces to obtain more information.

The Statistical Engineering Division of the NIST has scientists who were actively involved in the Zylon research, and who understand the data and variables associated with police use of body armour. We plan to work with them to devise a statistical approach to the Canadian model. In this phase, we will produce sampling guidelines for the number and types of aged vests for testing, as well as what populations of in-service vests their results represents. We anticipate a number of meetings with the SED in Gaithersburg, MD as part of this task.

Further statistics work is necessary to interpret ballistic limits tests results to estimate whether an aged armour has degraded to the point where its performance, and the performance others that it represents, may be questionable.

In addition to the anticipated no-cost involvement of the SED at NIST, we shall propose a modest budget for additional statistical consultation in this task.

3.4 Draft Protocol

In this stage, we will design the aged armour protocol and document it in manual. Note that based on our work in Phase I of this program, we now feel that we will be able to develop the protocol without the need for an extensive test program. Some tests will, of course, be eventually required in Phase III in order to verify the protocol, but at reasonable levels. We will study the science behind the newly drafted NIJ 0101.06 protocol for evaluating the degradation of artificially aged armour. Similarly the Home Office in the United Kingdom has developed new approaches to ongoing quality assurance batch tests of in-service vests. We have already initiated communications with representatives from the Home Office responsible for designing and carrying out their new protocols.

We anticipate that the protocol will describe the particular quantities of five-plus year old armour that needs to be tested, what those tests shall be, and how the test results compared to the certification level indicates what armour remains suitable for service.

For sake of economics and ease of testing availability, we intend that all ballistic tests reference current NIJ or common military test methods. We further anticipate that a presentation will be given to the CPRC and CACP, as well there being a review process and, if necessary, editorial revisions to the draft document.

A draft protocol for the replacement of aged armour, based on Canadian police, will be the final deliverable for this Phase 2 work.

4. Work Plan for Phase 3: Verification Testing Pilot Study

Following the development of the draft aged armour replacement protocol, it will be necessary to verify its feasibility via a pilot project. To this end, it is anticipated that one, or perhaps two forces will participate by volunteering to supply aged armour, identified from the earlier detailed ballistic armour data, for V50 lab testing and NIJ materials analysis. The tasks for this phase are described in the following sections.

4.1 Obtain Aged Armour from Police

For this verification pilot study, we think it best to target a force who would normally discard their used vests at the five year period. This way there is no cost to that force for supplying us with armour to test. It would be further advantageous if that force had a diverse number of makes and models for evaluation, so that a maximum number of fibres are included. We shall rely on the CPRC to assist with negotiating participation from a selected police force. We will work with personnel from that force who deal with vest procurement and disposal, using the draft protocol.

At this time, since the statistical process has not been designed yet, we will base our numbers on an anticipated 50 to 100 vests for testing.

Biokinetics and Associates Ltd. maintains a secure storage room at its test facility to ensure the security of these armours.

4.2 Document and Photograph

A database will be maintained of all vests used in this pilot project. This will include the documentation of all parameters associated with the vest's make, model, construction, age, condition, etc. Beyond documentation, the garment will be tagged and properly stored.

4.3 V50 Testing, NIJ Analysis

Each vest will be subjected to the standard NIJ 12-shot V50 ballistic test. All testing will be done at Biokinetics' ballistic test facility in Ottawa, ON. Specific coupons will be extracted for NIJ scientific analysis, packaged and shipped. We will not be responsible for the dissemination of the data garnered by the NIJ. That will remain their prerogative. However, a condition of the partnership will

be that the supplying police agency will have confidential access to the laboratory results.

Tested vests will be cut into unusable pieces by Biokinetics and Associates and discarded, or returned to the donating force if requested.

4.4 Report on Verification Protocol

The draft aged armour protocol guidelines will be applied to the data obtained in the ballistic testing. A report will be compiled describing the issues that arose in the project, and ways to remedy them in the future. The volunteer police force who participates in the pilot study might enjoy being able to extend the service life of some of its body armour by one year, after which the protocol is again enacted, and so on.

This report will be considered the final deliverable for the Phase 3 project.

5. Summary

The work completed under the Phase One is summarized as follows:

1. A review was provided of the NIJ and OLES investigation of aged armour activities in response to the Forest Hills failure of a bullet proof vest made with Zylon.
2. Manufacturer warranties for vests manufactured in Canada, and/or purchased by major Canadian police forces was investigated.
3. A tabulation of police force size and estimated number of vests in service was compiled. A more thorough survey could be managed in the future with increased participation by the CACP.
4. A brief overview of the statistical considerations associated with investigating the service life of aged armour was provided.
5. A work plan for Phase 2, the development of an aged armour replacement protocol, including budgetary estimates was provided. This included the plan for a research partnership with the NIJ and OLES.
6. A work plan for Phase 3, the validation of the work plan via a pilot project with one major police force, and estimates of 50-100 vests tested. This included partnership efforts with the NIJ and OLES to supply them with samples of Canadian aged armour for their research ambitions.

Appendix A: Major Canadian Police Forces Ballistic Vest Information

Police Force	RCMP	QPF	OPP	Halifax	Montreal
Contact	Andrew Wardroper	Regis Giesecke	Paul Powers	Tom Chambers	Regis Giesecke
Phone					
Approximatetly how many vests are currently in service?	18,000	5,000	5,000	500	3,500
What brand of vests are in service?	Unique RCMP specification	American Body Armour, Pacific Safety, Atlantic (now Ten4)	Pacific Safety	Safari Land (Lvl II)	American Body Armour, Pacific Safety, Atlantic (now Ten4)
What models are in service?		n/a	n/a	n/a	n/a
What is the typical service life of a vest?	7 years	10 years	No set life.	10 years	10 years
What quantity of decommissioned vests do you currently have available?	n/a	n/a	0	20	n/a
What is your understanding of the vest warranty?	7 years mandatory as per procurement specification.	5 years by manufacturer. QPF requests a batch test before accepting a new order and perform yearly tests on vests.	5 year on workmanship and construction but still pass ballistics.	5 year manufacturer warranty on construction.	5 years by manufacturer. Montreal requests a batch test before accepting a new order and perform yearly tests on vests.
Do you currently submit aged armour to any verification testing?	Yes, at 6 years random vests undergo ballistic verification tests to the RCMP test protocol.	Yes, after 10 years vest are tested and they pass.	No, they use non regular internal verification. Are implementing annual visual inspections.	No, they have done internal firing range testing of vests from 5-20 years with no complete penetration.	Yes, after 10 years vest are tested and they pass.

(Continued next page.)

(Continued from previous page.)

Police Force	Ottawa	Toronto	Winnipeg	Calgary	Edmonton	Vancouver
Contact	Bill Keeler	Diane Jeffries	Craig Davel	Kirk McCallum	Brian Kislavitch	Jim Lloyd
Phone						
Approximatetly how many vests are currently in service?	1,200	*	1,400	1,200	1,400	1,300
What brand of vests are in service?	Pacific Safety	*	Pacific Safety (Lvl II)	**	Second Chance (Lvl II & IIa. They are phasing out Lvl IIa)	Pacific Safety (level IIIA, jail staff Spike II. They still have older Level II vests being phased out.)
What models are in service?	UG2LGT8	*	UG204TW8	**	n/a	
What is the typical service life of a vest?	5 years	*	5 years	**	5 years	5 years
What quantity of decommissioned vests do you currently have available?	10-20	*	12-36	**	10-20	Varies
What is your understanding of the vest warranty?	Legal coverage of 5 years, after that PSP cannot take responsibility for protection and will not warranty or guarantee the product.	*	Legal warranty coverage of 5 years, however according to DuPont that can be stretched.	**	5 year replacement. They know vests are good for longer with proper care but the officers insist on replacement after 5 years.	5 years from date of manufacture for defects. Generally most concerns are observed in first months and are addressed promptly by manufacturers at no cost.
Do you currently submit aged armour to any verification testing?	Not at this time. They used to but are now following the OPP and Durham Police Service contracts.	*	No, they do all of their's when they are new at independent labs.	**	No. All replaced vests go to the US for recycling.	No formal testing. VPD range staff will informally shoot armour. Vests shot have ranged from armour into the 10-15 year period, current armour, and include units in poor condition.

* Biokinetics could not establish contact.

** Initial contact was made, he was not familiar with details. Further contact could not be established.

Appendix B: August 2007 Memo to the CACP

18 August 2007

Notice to CACP regarding the development of a protocol for aged soft body armour.

At the request of the CACP, the CPRC is investigating the life expectancy of soft body armour with respect to issues that include the manufacturer's warranty period and replacement time. Soft body armour typically is warranted for a period of five years, but the question remains what exactly is warranted and what violates this warranty. At present there is no performance standard that addresses the ballistic performance of armour as it ages, although the NIJ is currently working on a test protocol that artificially ages armour (NIJ 0101.06). Nevertheless, it will be likely be some time before full implementation of the new standard is in place, and even longer before these new products are purchased to replace existing soft body armour.

In the meantime, users of body armour are legitimately concerned about when to replace their existing product. Replacement at expiry of the warranty might be reassuring, but the costs of replacing fully serviceable units might be substantially reduced if it could be shown scientifically that they may be used safely beyond five years. To study this predicament, CPRC has collaborated with Biokinetics and Associates Ltd, an engineering consulting firm in Ottawa that specializes in human body protection systems. Biokinetics will be collecting information on the procurement and retirement cycles of soft body armour among Canadian Police Forces, outlining a statistical V50 and V-proof test program of used armour and consulting with the NIJ on their aged armour program. This phase of the work will be completed by end September. This will form the basis for the next phase of work whereby we will ask the various Forces for used body armour that has been retired from service be made available for ballistic testing. Any data published as a result of that testing will, of course, be kept completely anonymous although individual forces will have access to data on the specific vests they supplied.

We kindly request the Chiefs' cooperation in two quick ways. The first is to forward contact information (name, phone and email) to Biokinetics of the personnel in charge of procurement and decommissioning of soft body armour in your Force. The second is to direct that personnel to cooperate with this effort.

For your information, the questions Biokinetics will be asking will include the following:

1. Approximately how many vests are currently in service?
2. What brand of vests are in service (i.e. manufacturer and model) and to what level are they certified?
3. What is the typical service life of a vest? (Please explain all reasons for replacing or decommissioning a vest.)
4. What quantity of decommissioned vests do you currently have available?
5. What is your understanding of the vest warranty?
6. Do you currently submit aged armour to any verification testing?

Please provide this contact information to:

Laurin Garland (garland@biokinetics.com)
ph 613.736.0384 x 234
fax 613.736.0990

Christopher Withnall (withnall@biokinetics.com)
ph 613.736.0384 x 227
fax 613.736.0990

We further kindly request that the contact information be sent to Biokinetics by August 31, 2007.
Thank-you in advance for your speedy cooperation.

Steve Palmer,
Steve.Palmer@cprc.org 613.993.3996